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Biological Evaluation

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**EVALUATION OF THE SPRUCE, MOUNTAIN PINE, AND DOUGLAS-FIR BEETLE
POPULATIONS ON CARTER MOUNTAIN, SHOSHONE NATIONAL FOREST, WYOMING**

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ABSTRACT

Concurrent epidemics of spruce, mountain pine, and Douglas-fir beetle in the same area is at best extremely rare. This is the situation in the Carter Mountain assessment area, although each beetle epidemic is in a different phase.

A very intense and extensive epidemic of spruce beetle began west of the Continental Divide, which was discovered in 1999 on northwestern portions of the Shoshone National Forest and adjacent lands. Epidemic beetle populations made their way to the east, arriving around the year 2000 in the Carter Mountain assessment area. By the fall of 2003 or 2004, the spruce beetle epidemic will have run its course through the forests there, resulting in the death of almost all of the Engelmann spruce larger than 5 inches DBH and some smaller diameter trees. This mortality has occurred everywhere, regardless of tree density or species composition of the sites in which the attacked spruce had been living.

Because the spruce beetle has killed much of the overstory, the remaining live forest canopy is composed primarily of lodgepole, limber, and white bark pines and Douglas-fir, with some subalpine fir and a smaller amount of aspen. Rising beetle epidemics in the pines and Douglas-fir threaten to further reduce the forest cover and degrade stands managed for fiber production.

Plot, transect and walk through survey data are presented documenting forest insect and tree-disease conditions in the assessment area. Predictions are made as to the future impacts from these conditions. Recommendations are presented that address impacts consistent with management objectives.

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INTRODUCTION

This biological evaluation is in support of efforts to deal with the impact of an immense epidemic of the spruce beetle, *Dendroctonus rufipennis* [Kirby] (Order Coleoptera; Family Scolytidae). The overall area affected by the continued expansion of current spruce beetle populations covers several major drainages of northwestern Wyoming including portions of the Teton, Washakie, and North Absaroka Wilderness, Yellowstone National Park, the Shoshone National Forest, and associated state and private lands (Harris 2003; Harris et al. 2002; Harris et al. 2001).

Specifically, this evaluation concerns forest insect and tree disease conditions on lands included in the assessment area of the predecisional document Carter Mountain Vegetation Management Environmental Assessment, Shoshone National Forest, Wapiti Ranger District, Park County, Wyoming (USDA Forest Service 2003). In addition to fieldwork necessary to evaluate conditions, forest health management staff collected data on reforestation potential to assist the Shoshone National Forest and the project silviculturist. That data will not be included here.

This biological evaluation discusses populations of three tree-killing bark beetle species in the family Scolytidae, genus *Dendroctonus* --- the spruce beetle (SB), the mountain pine beetle, *Dendroctonus ponderosae* Hopkins (MPB), and the Douglas-fir beetle, *D. pseudotsugae* Hopkins (DFB) --- because they all were found to be at epidemic status in the assessment area. Tree disease conditions are also discussed. Most of the affected land is publicly owned and is administered by the Shoshone National Forest, with state and private lands intermixed.

The focus of this Biological Evaluation is threefold, as follows:

- Describe the status of ongoing bark beetle epidemics and tree disease conditions within the assessment area.
- Discuss the susceptibility of forested stands for continued infestation by these bark beetles and describe the potential for growth or decline of beetle populations and associated tree mortality.
- Make recommendations for future treatments consistent with the objectives and proposed action alternatives contained in the predecisional Environmental Assessment.

Spruce Beetle

The spruce beetle is the principal natural agent that can create landscape level disturbances in the spruce forests of western North America (Holsten et al. 1999). Sporadic spruce beetle epidemics have killed extensive forested areas in parts of western North America, including Alaska, western Canada, Colorado, Idaho, Montana, and Utah (Holsten et al. 1999). Such epidemics commonly develop in windthrown timber. Spruce beetle populations can increase dramatically within windthrow, from which they emerge to attack and kill standing, living spruce. Like fire and wind, the spruce beetle is a natural, though destructive, means for recycling old forests and for making way for new forests (Furniss and Carolin 1977).

Normally, this native beetle is present in small numbers in weakened, diseased or wind thrown spruce, large pieces of logging slash, and fresh stumps. Individual or small, scattered groups of standing trees may be killed, creating snags and gaps in the forest canopy. The spruce beetle infests all species of spruce within its geographic range and has a generation time of 1, 2 or 3 years, with 2 years being the most common (Holsten et al. 1999). Natural enemies, weather,

competition, host tree resistance and other factors combine to keep beetle populations at low levels, but disturbances in susceptible spruce/fir stands can trigger the development of spruce beetle epidemics.

Stands are highly susceptible to spruce beetle epidemics when the following conditions exist: basal area > 150 square feet per acre; average diameter at breast height > 16 inches for all live spruce; proportion of spruce in the canopy > 65%; and physiographic location in a well-drained site in a creek bottom (Schmid and Frye 1976).

Spruce beetle epidemics are thought to occur every 100 – 300 years. Within one area of about 8,600 acres on the White River National Forest of northern Colorado, three spruce beetle epidemics were evident since 1700 (Veblen et al. 1994). As determined from this data, the time interval between epidemics in a particular stand is 116 years. This time interval is considered reasonable by Schmid and Mata (1996), who comment that the interval could be longer if the stand was completely killed by the previous epidemic and shorter if the previous epidemic caused limited spruce mortality. As determined in the same study on the White River National Forest, the time interval during which all stands in an area are affected by epidemics is 259 years (Veblen et al. 1994). The return interval of multiple stand epidemics is dependent upon large acreages of spruce growing into an old, dense condition, susceptible to spruce beetle, and upon the occurrence of a triggering disturbance, such as windthrow, that provides the spruce beetle population the opportunity to increase from its resident or endemic level (Schmid and Frye 1977).

Forest renewal following large-scale spruce beetle epidemics is thought to be via the release of previously suppressed small-diameter sapling and seedling trees. As long as spruce and subalpine fir is abundant in the subcanopy, spruce beetle epidemics will favor the recruitment of both species into larger size classes (Veblen et al. 1991). Based on relative abundance and their differing life-histories, predominance by spruce or subalpine fir is thought to oscillate in wave-like patterns over long time spans (see discussion and references in Schmid and Hinds 1974 and Veblen et al. 1991 and 1994). Species composition post-epidemic can be altered by the following factors: (1) composition of the stand at the time of the epidemic; (2) intensity of the epidemic in term of trees per acre killed; (3) size of the epidemic in terms of acres; and (4) time and intensity of logging (Schmid and Hinds 1974). In seral stands, spruce beetle epidemics accelerate succession towards shade-tolerant tree species. The predominance of accelerated growth following a spruce beetle epidemic, instead of new seedling establishment, is a major contrast with the pattern of stand development following fire (Veblen et al. 1991).

The Mountain Pine Beetle

Like the congeneric spruce beetle, the mountain pine beetle is a native species of tree-killing bark beetle that feeds on the inner bark of mature coniferous trees. Hosts include lodgepole, ponderosa, and western white pines, including white bark and limber pines, among others (Amman et al. 1989). The mountain pine beetle generally has one generation per year. Natural enemies, weather, competition, host tree resistance, and other factors combine to keep beetle populations at low levels such that tree mortality is usually barely evident. Relative population size naturally fluctuates between two modes, called low or “endemic” and outbreak or “epidemic”; outbreak populations periodically arise, causing widespread and intense tree mortality that alters the forest structure.

Outbreaks of MPB frequently develop in lodgepole pine stands that contain well-distributed, large diameter trees (Amman et al. 1989). Highly susceptible stands of lodgepole pine are those with the following characteristics: average diameter at breast height > 8 inches; average age > 80 years; and a suitable climate for beetle development based on a low elevation-latitude combination

(Amman et al. 1977; Schmid and Amman 1992 and references therein), which equates to elevations between 7,500 and 8,250 feet in northern Wyoming.

Whitebark and limber pines, hereinafter collectively referred to as “white pines”, are preferred hosts for mountain pine beetle over lodgepole pine. Brood production in white pines is 2 – 7 times greater than it is in lodgepole pine (Cerezke 1995). Mountain pine beetle will readily switch from white pines into lodgepole pines when the white pine host supply has been somewhat depleted.

Unlike the spruce beetle, MPB population epidemics are not triggered by obvious disturbances such as windthrow. The development of epidemic populations of MPB is not well understood. Suffice to say that as stand susceptibility to MPB increases with time, the effectiveness of natural control decreases and epidemics develop (Furniss and Carolin 1977). MPB epidemics are more frequent for a given stand and area, as compared with spruce beetle. This reflects the differing characteristics of their host tree species, such as successional status and longevity. The mountain pine beetle ranks first in destructiveness among the bark beetles of the West (Furniss and Carolin 1977).

The Douglas-fir Beetle

Another native insect, the Douglas-fir beetle infests and kills Douglas-fir throughout its range in North America. The Douglas-fir beetle has one generation per year (Schmitz and Gibson 1996). Typical low-level beetle populations reproduce in scattered trees that are highly stressed, such as windfall, defoliated or fire-scorched trees (Furniss 1962; Furniss 1965; Schmitz and Gibson 1996). If enough suitable host material is present, beetles can increase in the stressed trees and infest nearby healthy trees (Furniss et al. 1981). Douglas-fir beetle attacks are most successful on older, larger trees found in high-density stands that contain a high percentage of Douglas-fir in the overstory (Schmitz and Gibson 1996).

The Context of the Bark Beetle Situation

The word “*Dendroctonus*” translates from Latin as “tree killer”. Like nearly all species in the genus *Dendroctonus*, the spruce, mountain pine, and Douglas-fir beetles infest and kill mature trees. As our western forests grow older and increasingly show the effects of fire suppression and other forest management practices subsequent to Euro-American colonization, larger contiguous landscapes in the Rocky Mountain area have become simultaneously susceptible to bark beetle epidemics (Samman and Logan 2000). Susceptible forests await only a trigger before a bark beetle epidemic develops. Across the Rocky Mountains and intermountain west, the table is set for bark beetle feasts.

Recent conditions reports for the Rocky Mountain Region show increasing epidemic activity by tree-killing bark beetles in Colorado, South Dakota, and Wyoming (Harris 2003; Harris et al. 2002; Harris et al. 2001). Moreover, this does not include information on the many current, large bark beetle epidemics in other portions of the Rocky Mountains and intermountain west. These beetle episodes underscore the fact that much of the forest in the Rocky Mountain Region is mature to very old (USDA Forest Service 1987). As time passes, the susceptible mature forest areas are increasingly vulnerable to a disturbance that will recycle the old forest to a young forest.

Age by area distribution of lodgepole pine stands across the Rocky Mountain Region and in the Shoshone National Forest is heavily skewed towards ages in excess of 80 years (USDA Forest Service 1987). Most of these stands have average diameters in excess of 8 inches and many are in suitable climatic areas for MPB epidemics. It is not surprising that the total number of pines killed

by MPB has been increasing. The context of current widespread susceptibility and recent MPB behavior is that there is a lot of pine forest that is becoming more extensively and intensely affected by epidemics. This same case can be made for spruce and Douglas-fir forests on the Shoshone National Forest and elsewhere in the Rocky Mountain Region and intermountain west --- these forests are relatively old and ripe for disturbance.

A reasonable conjecture is that the larger an area which becomes susceptible at one time, the more severe will be the inevitable tree-killing bark beetle epidemic. This is partly because more food is readily available without the mortality that can result from beetles search to find new hosts. Weather permitting, the larger the amount of beetle food in one place at one time, the more of it the beetles are likely to consume in one episode. Creating a mosaic of ages and species across a landscape will mitigate large-area impacts.

Significant episodes of tree-killing by bark beetles will result in the regeneration of mature forests into younger-aged forests. These beetle-caused disturbances will shift tree species composition, depending on the extent and intensity of mortality. Many other impacts result from tree-killing bark beetle epidemics in addition to the creation of large numbers of dead trees in a short time span (Schmid and Amman 1992; Schmid and Mata 1996; Samman and Logan 2000). Regeneration and herbage production will increase in beetle-caused openings in the forest. Annual stream flow and water yield may increase where an epidemic is extensive and intense. The green foliage of recently attacked trees will dry out, fade to a red color, and remain on the tree for one to two years. In addition to a visual impact, these red needles will provide a temporary increase in dry, flammable material in the forest canopy. The killed trees will then begin to fall down, increasing the coarse woody debris and fuel loading in the forest.

Extended drought may be playing a role by lowering trees' ability to defend themselves from attack. However, there can be no bark beetle epidemic if there is not a sufficient food base in the form of susceptible stands and groups of stands. An overstocked stand where moisture and nutrients are limited by intertree competition will result in a sort of "functional drought" where trees become susceptible to infestation. History-based research has thus far not shown a consistent relationship between drought and epidemics of spruce, mountain pine, or Douglas-fir beetle. Research results have consistently shown that stand density and growth rate among mature host trees is associated with attack and mortality from western conifer-killing bark beetles.

MATERIALS AND METHODS

Aerial Detection Surveys

In a fixed wing aircraft, observer(s) mapped the approximate location, apparent cause, host tree, and estimated intensity of forest insect and tree disease impacts. Only recent impacts were recorded to avoid "double counting". Surveys were timed to occur within the appropriate "biological window", that moment in time when the signs of the most important organism(s) were most visible. In this case, the sign of choice was fading foliage due to bark beetle attack.

General aerial detection surveys can cover large acreages rapidly and at relatively low cost per acre. Survey goals are to detect and describe, not to quantify, forest insect and tree disease impacts. Consecutive annual aerial surveys over the same area provide good trend information.

Inventory Survey

A plot-based inventory survey method was developed using established procedures described in the Rocky Mountain Region's field guides for common stand exam. The two survey objectives were

to assess tree-killing bark beetle infestation level and reforestation potential based on seedling and sapling trees.

Variable radius plots were installed using either a 10 or 20 basal area factor angle gauge or prism. Centered within each variable radius plot, a fixed radius plot covering 1/100th acre was measured. Variables recorded are listed below.

Variable radius plot = trees 5 inches or greater in diameter at breast height (DBH):
species; status (live or dead); height; bark beetle activity (attacked or unattacked);
timing of bark beetle attack (current year, 1 year ago, 2 years ago, older); presence
and type of disease-causing organism

Fixed radius plot = trees greater than 1 inch and less than 5 inches DBH (saplings):
number per species; average height per species; average DBH per species

Fixed radius plot = trees less than or equal to 1 inch diameter at root crown (seedlings):
number per species

Trees that died approximately five or more years ago were excluded.

Target sites for inventory survey were selected based on a lack of relatively current inventory and to broadly cover the areas proposed for treatment in the predecisional Carter Mountain Vegetation Management Environmental Assessment (USDA Forest Service 2003). Plot centers were either predetermined using a Geographic Information System map with coordinates or randomly in the field by traversing predetermined distances along a preselected azimuth.

From one to five plots were installed within a site. In some instances, only the variable radius plot data were collected. For some plots, the fixed radius plot, instead of being 100th acre, was as follows: a 1/50th acre fixed radius plot used to measure saplings and a 1/300th acre plot embedded within that to measure seedlings.

Transect Survey

With this survey method, two or three observers walk through a site along a predetermined azimuth while collecting data on bark beetle attacks within a 1-chain (66 foot) corridor centered on the azimuth. Tree species, beetle species, and timing of attack (see above) were recorded for all trees attacked or dying within the last five years. At 10-chain (660 feet or 0.13 mile) intervals, a variable radius plot was installed as described above, with the exception that height data were not collected. Therefore, transect lines covered one acre (1 X 10 chains = 43,560 square feet) before each plot was installed.

Walk-through Survey

Many sites were walked through with no tree data recorded, although some data were occasionally taken to facilitate estimates of bark beetle infestation level. Walk through surveys were usually done in the company of the project silviculturist, in order to integrate information on current and estimated future bark beetle impacts into proposed prescriptions for treatment.

RESULTS AND DISCUSSION

Aerial Survey

General aerial detection surveys were conducted over the Carter Mountain area in 1996, 1999,

2000, 2001, 2002, and 2003. The 1996 survey detected little activity, primarily due to the mountain pine beetle. An increasing trend in acreage affected by bark beetles, especially in 2000 and 2001, was evident from these surveys.

Aerial surveys were done July 10 - 15 in 2002 and during the week of July 14 in 2003. Results from 2003 have just been received and have not yet been evaluated.

The 2002 aerial survey results showed significant DFB, MPB, and SB activity on Carter Mountain. Three groups numbering 100, 100, and 200 killed trees were mapped and attributed to DFB, located at lower elevations in the northwest portion of the assessment area. Group kills larger than about 10 trees are characteristic of an epidemic DFB population that has been building for a few years in order to kill such large groups of trees. MPB activity was tied to white bark and limber pines and coded as a complex including the beetle, white pine blister rust and/or dwarf mistletoe. Significant portions of the white pines component were so noted. No MPB in lodgepole pine was mapped. Subalpine fir decline was also not detected and mapped. Much of the remaining portion of the assessment area was mapped to indicate mortality from spruce beetle. The intensity of the impact of SB was seen to be relatively light, with a few moderate sized polygons of as many as three trees per acre killed. In sum, most of the assessment area was considered to have some impact from bark beetles.

The 2002 aerial survey results match the situation found on the ground in 2003 quite well, with one exception. As the following sections will demonstrate, the number of trees killed by spruce beetle was significantly underestimated by the 2002 aerial survey (Schaupp 2003). The acreage affected was accurate, however, involving almost the entire spruce component.

The visual signature of spruce beetle attack is among the most difficult to detect during aerial surveys. Fading spruce trees lose their needles quickly and do not fade as brightly as the foliage on other conifers killed by bark beetles. In addition, the detection flight probably occurred before fading peaked in the spruce. Timing surveys is difficult due to both this variation and scheduling the plane and surveyor.

These annual surveys detected trees attacked and killed by the Douglas-fir and mountain pine beetles the previous year, because green foliage fades to yellow and red one year after successful beetle attack. In the case of the spruce beetle, such fading usually occurs two years after successful attack. In general, by the time that tree fading peaks, the bark beetles have exited their fading brood trees and are attacking green trees. Current year attacks can only be detected from the ground.

Inventory Surveys

Inventory surveys were performed between June 5 and July 16, 2003.

Plot data show that recent conifer mortality due to bark beetle attack is widespread across the assessment area (Table 1). Trees killed by bark beetles were found in 24 of the 31 inventory survey plots, accounting for 62% of the 297 plot trees greater than 5 inches DBH. Basal area reduction by bark beetles averaged 58% in these plots, although there was a lot of variation. Such a high level of bark beetle-caused mortality was possible because the plots carried a significant amount of beetle food in the form of older, larger diameter trees growing in a relatively dense condition. Overall, the plot trees averaged 13.1 inches DBH and covered 132 square feet of basal area.

Spruce beetle was by far the most common bark beetle encountered in the inventory surveys

(Table 1 and Table 2). Seventy-four percent (23/31) of the plots contained susceptible-sized spruce and all but one of those plots had spruce beetle-caused mortality. Beetles killed nearly all of the spruce trees in the plots.

Although the spruce beetle impact is the most obvious and intense on Carter Mountain (Schaupp 2003), the assessment area also has ongoing epidemics of mountain pine beetle in white pines,

Table 1. Inventory plot data from Carter Mountain, Shoshone National Forest, Wyoming in 2003 **

Resource Information System Data			Size		Density		Percent of Initial Plot Trees Killed by Bark Beetles			
Location	Site	Cover Type	Plot	DBH all	BA all	BA alive	% spruce	% pine	% Douglas-fir	% subalpine fir
436204	0021	Lodgepole pine	1	13.3	60	60	*	0	*	*
436204	0021	Lodgepole pine	2	10.9	80	80	*	0	*	*
436204	0023	Lodgepole pine	1	13.6	80	40	100	33	*	*
436204	0023	Lodgepole pine	2	16.5	80	80	100	0	0	*
436208	0005	Spruce/fir	17	15.2	260	40	100	0	91	*
437202	0010	Grassland	1	14.5	80	0	*	100	*	*
437202	0010	Grassland	2	15.9	100	20	100	86	0	*
437202	0010	Grassland	3	14.1	110	90	*	18	*	*
437202	0016	Douglas-fir	G	15.4	170	10	100	*	0	*
437202	0016	Douglas-fir	H	12.0	160	40	100	60	75	*
437202	0021	Lodgepole pine	1	12.4	140	80	100	*	50	*
437202	0021	Lodgepole pine	2	14.7	160	20	100	*	0	*
437202	0021	Lodgepole pine	3	12.7	40	40	*	0	0	*
437202	0021	Lodgepole pine	4	12.1	120	20	100	0	100	*
437202	0021	Lodgepole pine	5	9.6	220	220	*	0	0	*
437202	0040	Lodgepole pine	6	14.0	120	20	83	*	*	*
437202	0040	Lodgepole pine	7	11.2	120	120	0	0	*	0
437202	0040	Lodgepole pine	8	10.2	140	60	100	100	*	*
437203	0001	Spruce/fir	1	11.9	120	20	82	*	*	0
437203	0001	Spruce/fir	2	9.9	120	40	80	*	*	0
437203	0001	Spruce/fir	3	12.1	220	130	100	*	*	0
437203	0001	Spruce/fir	4	14.9	110	10	100	*	*	0
437203	0003	Spruce/fir	1	11.7	120	60	80	50	*	0
437203	0003	Spruce/fir	2	14.5	230	130	100	*	*	0
437203	0003	Spruce/fir	3	14.6	230	0	100	100	*	*
437203	0003	Spruce/fir	4	12.0	110	20	100	*	*	0
437206	0001	Douglas-fir	12	11.4	220	20	90	*	100	*
437206	0001	Douglas-fir	13	14.7	120	80	100	0	33	*
437206	0001	Douglas-fir	14	15.0	60	60	*	*	0	0
437206	0002	Douglas-fir	15	10.4	60	20	50	*	100	*
437206	0002	Douglas-fir	16	13.4	120	120	*	0	0	*

** **Location Key within the assessment area:** 436204 (old Belknap timber sale area) and 437208 (USFS boundary on FSR 474) in the west; 437202 (Hidden Lake area) and 437203 (Long Park) in the middle; 437206 (Pete Miller Park area) in the east.

Key to Abbreviations in Table 1: DBH = diameter at breast height in inches; BA = basal area in square feet per acre; "BA all" refers to all trees in the plot, living or dead within the last 5 years; "BA alive" refers to living, unattacked trees.

and Douglas-fir beetle in Douglas-fir. Eleven plots (35%) contained either white bark or limber

pinus (Table 1). Mountain pine beetle killed a little over half of these white pines (Table 2). Thirteen plots (42%) had lodgepole pine, of which less than one quarter were killed by mountain pine beetle. Fifteen plots (48%) had some Douglas-fir, of which about half were killed by Douglas-fir beetle. Only nine plots (29%) had any subalpine fir. Only one of these 43 subalpine fir was dead, cause unknown, but not due to bark beetles.

Mortality from spruce beetle activity has been decreasing in the inventory survey plots, as demonstrated by data on the year of fatal bark beetle attack (Figure 1; Table 2). This is one indication that the epidemic in spruce is declining.

Another indication of epidemic decline is illustrated by Table 3, which shows a decline in average diameter of trees killed by spruce beetle as the epidemic has progressed. Spruce beetle prefers trees > 20 in DBH to trees of 6-inch to 8 inch DBH (Schmid and Frye 1977). As the larger trees become depleted and as the beetle population becomes excessively abundant, smaller diameter trees are attacked (Massey and Wygant 1954), although attacks do not progress down through the diameter classes in a linear way (Schmid and Mata 1996). The net result of this is that large epidemic spruce beetle populations reduce the average diameter of affected stands, in addition to many other impacts (Schmid and Mata 1994; Schmid and Amman 1992). Massey and Wygant (1952) report that spruce beetle infested trees as small as 2 inches DBH during a severe epidemic in Colorado in the 1940s. Although no evidence for attack on such small trees was seen in the plots, it remains a possibility in the next year or two.

Table 2. Timing and degree of bark beetle activity in inventory survey plots, Carter Mountain, Shoshone National Forest, Wyoming

Bark Beetle	Host Tree	Year of Fatal Bark Beetle Attack				Total Attacked *	Not Attacked
		Older	2001	2002	2003		
Spruce beetle	Engelmann spruce	50	52	23	8	137 (96%)	6
Mountain pine beetle	White pines	1	3	10	4	18 (58%)	13
Mountain pine beetle	Lodgepole pines	0	0	1	4	6 (16%)	31
Douglas-fir beetle	Douglas-fir	3	0	5	15	23 (53%)	20

* Not all attacked trees were classified by year of attack

The inventory plot data suggest that the decline of the spruce beetle epidemic is a function of stand depletion. There simply are few living trees left to attack. Most living spruce trees are at or are below the smallest diameter within which beetle reproduction can occur. The spruce beetle has consumed nearly all the food available in the plots.

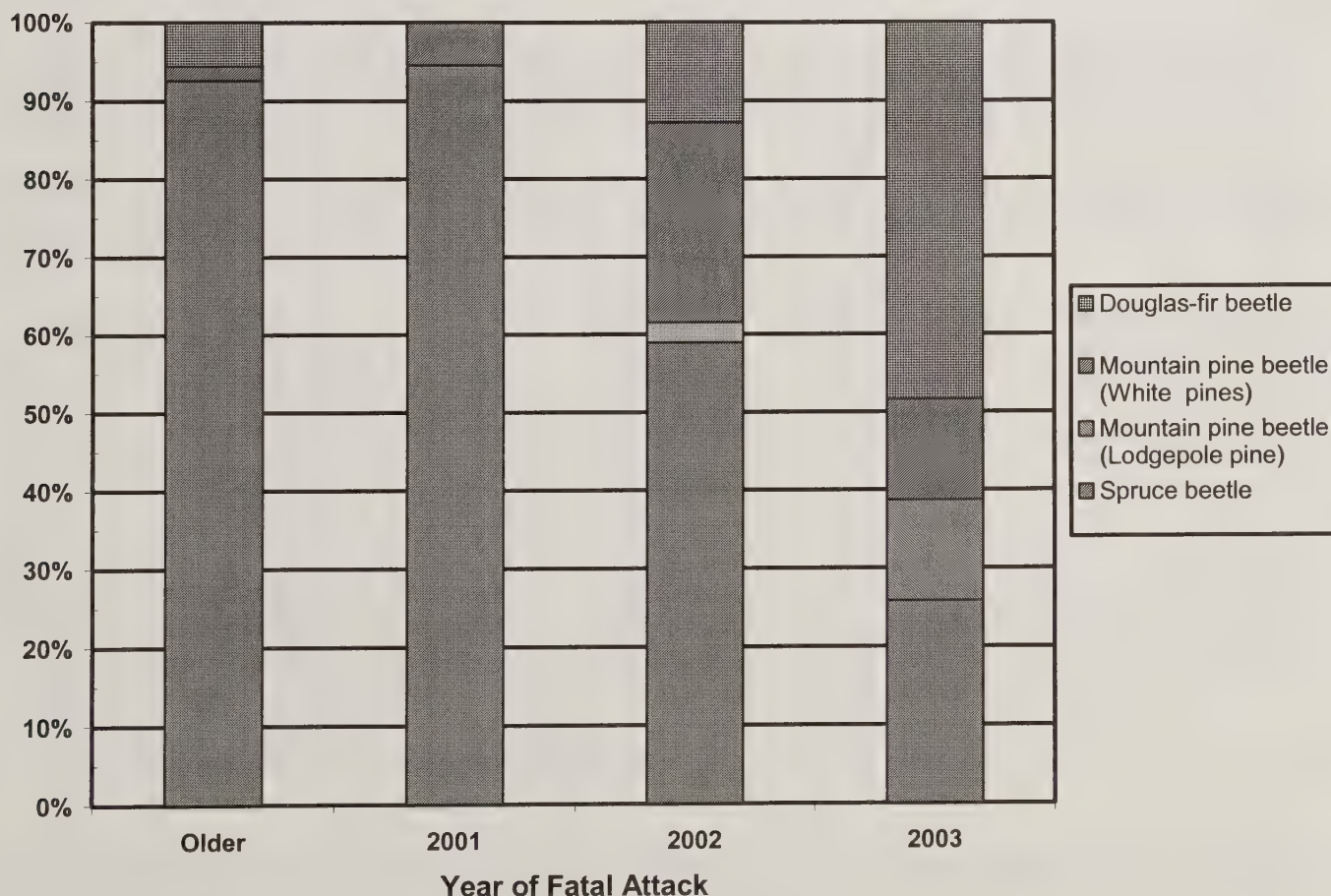
Table 2 and Figure 1 show increasing activity since 2001 by mountain pine in white pines and by Douglas-fir beetle in Douglas-fir. The 2003 attack data is incomplete, as well, because the flight and attack periods of MPB and DFB had not yet finished. Additional pines and Douglas-fir will be attacked in 2003, so the plot data underestimate both beetles' impact. This underestimation can be locally drastic.

Table 3. Average diameter at breast height (DBH in inches) of Engelmann spruce trees killed by spruce beetle by year of fatal attack, Carter Mountain, Shoshone National Forest, Wyoming.

Attack YEAR	Older	2001	2002	2003	Unattacked
Average DBH	14.4	14.9	11.4	8.7	7.3
(Std. Error)	(3.0)	(2.0)	(3.2)	(1.9)	(3.2)

For example, on June 12, a 66 X 660 foot, one acre transect was surveyed in location 437208, site 0005, uphill and south of the meadow at the USFS boundary on the Carter Mountain main road (FSR 474). No 2003 Douglas-fir beetle attacks were found within the surveyed area. By July 8, less than one month later, DFB had attacked eight of the eleven Douglas-fir within a 20-BAF plot placed inside the transect survey area (Table 1). A walk through survey confirmed that the Douglas-fir beetle was currently attacking or had just attacked every Douglas-fir larger than 5 inches DBH in the general area.

Figure 1. Bark beetle attack by species and year in inventory survey plots, Carter Mountain, Shoshone National Forest, Wyoming.



Obviously, surveys made after most attacks had occurred this year would provide better estimates of current bark beetle activity. In the case of SB, MPB and DFB, such a survey would begin around early September, 2003. Such a delay was not practical in the case of Carter Mountain. It is important to remember that more pines and Douglas-fir have been attacked by tree-killing bark beetles in 2003 than the information in this evaluation shows.

Transect Survey

Two transect surveys were completed. The first is mentioned in the section above as an example of fieldwork that was too early in the year (June 12) to survey accurately the current Douglas-fir beetle activity. Data from that transect show 38 SB-killed spruce, 5 DFB-killed Douglas-fir, and 3 MPB-killed white pines over the one acre transect. Consistent with the inventory plot data, all but five of the SB attacks were made in 2001 or before. The plot data were taken July 8 and are summarized in Table 1 for location 437208, site 0005.

The second transect survey focused on mountain pine beetle and was conducted on July 16. This transect was placed at the ecotone between a white pines site and a lodgepole pine site near the end of the Carter Mountain main road (FSR 474), east of and downhill from Long Park. At the time of the survey, MPB was exiting brood trees from 2002 attacks and entering new trees, making 2003 attacks. The plot data, taken at the end of each segment, appear in Table 1 under location 437202, site 0010. Although the Resource Information data classify this site as primarily grassland, the area surveyed was covered by larger diameter pines and spruce at 80 – 120 square feet per acre of basal area.

The first transect segment passed through a pure white pines stand north of the road, extending southwest along the bottom third of a south-facing slope. Along this acre, 49 white pines were attacked by MPB, mostly in 2002 and 2003 (Table 4). Continuing along the same azimuth, the

Table 4. Bark beetle activity by year of fatal attack along a transect survey, 66 X 660 feet or one acre per segment, at a white pines/lodgepole pine ecotone on Carter Mountain, Shoshone National Forest, Wyoming, on July 16, 2003.

Segment	Host Tree	Beetle	Older	2001	2002	2003
1	White pines	MPB *	0	3	36	10
2	White pines	MPB	0	8	44	6
	Lodgepole pine	MPB	0	0	3	1
	Engelmann spruce	SB **	0	0	2	0
3	White pines	MPB	0	0	1	2
	Lodgepole pine	MPB	0	0	3	11
	Engelmann spruce	SB	1	2	27	5

* MPB = mountain pine beetle, *Dendroctonus ponderosae*

** SB = spruce beetle, *Dendroctonus rufipennis*

second segment passed mostly through pure white pines, but ended-up closer to the road in a more mixed conifer area. Again, recent MPB activity was significant in the white pines (Table 4), but

MPB had also recently moved into a few lodgepole pine. Some firewood cutting had taken place in that area, indicating additional past MPB activity. The third segment was offset across the road in the bottomland, extending back to the northeast. This is where the white pines were no longer predominant and lodgepole pine and some spruce were more common. In this segment, MPB activity was less than in the two previous segments and consisted primarily of 2003 (current) attacks on lodgepole pine. It is clear that the large and increasing mountain pine beetle population in the white pines is moving into the lodgepole pine.

Because limber pine is superior food for MPB and because these enlarged beetle populations will switch into lodgepole pine, the situation documented by this transect survey constitutes a significant hazard to susceptible lodgepole sites adjacent to MPB-infested white pine sites. The dense, larger-diameter condition of the adjacent lodgepole site (location 437202, site 0011) foretells a high mortality rate, should the epidemic continue in the lodgepole pine.

Walk-through Surveys

Walk through surveys were conducted between June 5 and July 16, 2003. In all cases, these walk through surveys were in the company of Jan Burke, Rocky Mountain Region National Fire Plan Silviculturist, or Dennis Eckardt, Shoshone National Forest Timber Staff Officer and Silviculturist. In this way, a lot of the assessment area proposed for treatment was examined.

It is not possible to detail every place where walk through surveys occurred. The following lists locations and sites within the assessment area that were traversed to some extent:

West portion: old Belknap Sale area and areas to the west, location 436204, sites 0013 - 0016, 0021.

Central portion: southern edge of Sawmill Park, location 436209, and location 436210, sites 0001 and 0002; north edge of Long Park, location 437203, site 0013; Marquette Creek drainage, location 437201, sites 0007, 0008, and location 437202, sites 0007, 0009 - 0011, 0015, 0016.

East portion: Carter Creek drainage, location 437202, sites 0021, 0022, 0024 - 0026, 0028 - 0031, 0032 (Pete Miller Park), 0039, 0044; location 437206, site 0008.

A summary of field notes and observations is discussed below.

Spruce beetle

Many infested green spruce had both immature and adult spruce beetles under the bark in early June, 2003. These trees also commonly had some bark removed on the lower stem, evidence of woodpeckers feeding on beetles. Needle drop was just beginning on these densely attacked trees.

It is most likely that these trees, attacked in 2002, yielded some adult spruce beetles in one year and that other beetles will require two years to complete development. While the 2-year life cycle predominates in most areas, varying proportions of the brood do develop in 1 year, temperatures permitting (Massey and Wygant 1954; Holsten et al. 1999). A reduction by half in the time required for a spruce beetle generation allows a 100% per year increase in the rate of growth. This may have contributed to the high degree of host tree mortality achieved by the spruce beetle over such a short time span. Large areas of susceptible forest and mass immigration of spruce beetles from an immense epidemic to the west are likely the more important reasons for the extremely high level of spruce mortality across the entire assessment area in a short time.

Very few spruce were killed more than five years ago, judging from their condition (Schaupp 2003). The inventory plot data agrees well with walk through survey results. While there are some few

green spruce trees above 5 inches DBH, most have already been attacked in 2003 or are likely to be attacked, judging by ongoing beetle activity.

Isolated spruce growing within other cover types and in mixed stands had been beetle-killed. One example is in the Marquette Creek drainage downstream from Long Park (location 437202, site 0011). This site is dominated by lodgepole pine, with mature spruce of moderate diameter scattered throughout, accounting for no more than 5 - 10% of the trees. Yet, every single spruce there had been killed.

Stand density seems to have had no effect on the pattern of mortality, as viewed from near the end of the spruce beetle epidemic. Isolated spruce in low residual basal area portions of the 1990 Carter State Timber Sale in Sawmill Park, pure spruce at 100 –120 BA in areas of the 1994 Carter Mountain 1 Timber Sale, spruce mixed with some subalpine fir in 220 BA areas south of Long Park --- all were killed. This does not mean that stand density is irrelevant with respect to spruce beetle-caused mortality. Rather, this shows that, if there are enough spruce beetles in one place at one time, all the susceptible host trees will be killed. The short duration, extreme intensity, and broad extent of this beetle-caused mortality episode is remarkable.

Mountain pine beetle

Pines attacked by mountain pine beetle were found across the entire assessment area. The level of pine mortality is far less at present than the spruce situation. Most of the mountain pine beetle activity is recent, having occurred in 2002 and continuing in 2003, with additional attacks expected this year. While the mountain pine beetle epidemic is at an earlier stage than that of the spruce beetle, expansion and increase of the epidemic is highly likely, given the presence of susceptible pine stands in the assessment area and apparently favorable weather and other factors.

At present, most of this epidemic is in white pines. MPB activity could be found wherever there were white pines --- isolated clumps of white pines growing on open grassy areas and those found in dense stands had been or were being attacked. It is in the dense areas that mortality is most intense and extensive. Telltale signs on large white pine snags showed that this is not new. As noted in the Transect Survey section above, MPB switching from white pines to lodgepole pine is in progress and constitutes a significant hazard. In addition to the area near Marquette Creek where a transect survey was conducted, this situation occurs on the knob above the old Belknap sale area (location 436204, sites 0003 and 0004) and in areas in the Bull Creek drainage to the southeast of the access road (on FSR 474) that are visible during the ascent before passing into dense forest and crossing onto the National Forest (location 436207, site 0001). It is likely that there are a few more such situations within the Carter Mountain assessment area.

MPB activity in lodgepole pine was also evident across the entire assessment area, although varying on a local scale and present to a lesser degree than in the white pines. Stands and areas adjacent to and distant from white pines had multiple group kills of 1 - 5 lodgepole pines. Examples of this include but are not limited to the following: the Belknap Creek drainage in location 436204, sites 0013, 0014, 0016; the southwest edge of Sawmill Park (location 436210, sites 0001 and 0007); the southeast edge of location 437202, site 0011, not far from Long Park in the Marquette Creek drainage; and all along the ATV trail from the access point off Carter Ranch extending east to Pete Miller Park.

Disease-causing organisms impacting pines

During the walk through surveys, several other organisms were detected that are having a significant impact on the pines in the assessment area. Some affect susceptibility to mountain pine beetle attack.

White pine blister rust

White pines afflicted by the disease white pine blister rust were found across the entire assessment area. Although no formal assessment was undertaken, moderate to light infection was ubiquitous. Branch infections and branch mortality and flagging were commonly observed. Top kill was occasionally found. Mortality of sapling and pole-size trees from blister rust was rarely noted, however.

White pine blister rust, caused by the invasive, exotic fungus *Cronartium ribicola* J.C. Fisch., is a serious disease of 5-needle pines, including limber and white bark pine. The fungus is transmitted to pines by spores coming from its obligate alternate host, shrubs in the genus *Ribes* (gooseberry and currant). This spore transmission step is thought to occur over relatively short distances. *Ribes* spp. plants were commonly found growing at the base and in the shade of infected white pines. The fungus life cycle continues when spores from pines infect *Ribes* spp. The transmission step from pine to *Ribes* spp. can occur across vast distances.

Comandra blister rust

Lodgepole pines affected by the disease comandra blister rust were found across the entire assessment area at light to moderate levels. Stem and branch cankers, flagging, top kill, and mortality were observed due to infection.

Comandra blister rust is caused by the fungus *Cronartium comandrae* Pk. and is one of the more important diseases of lodgepole pine in the Rocky Mountains, especially in Wyoming. This native fungus alternates between a hard pine host and the herbaceous plants comandra or bastard toadflax, *Comandra umbellata*. Larger lodgepole pines, usually in the higher crown classes, are most frequently damaged. Infection levels decrease with increasing distance from sagebrush, where Comandra occurs. Trees with stem cankers produce significantly fewer cones and seeds than healthy trees. There is some evidence that mountain pine beetles select lodgepole pines trees infected by comandra blister rust (Rasmussen 1987).

Dwarf mistletoe

Lodgepole pines infected by dwarf mistletoe were found across the entire assessment area at levels that ranged from light to very heavy for stands and individual trees. Brooms, cankers, top kill, and mortality due to dwarf mistletoe were found.

Lodgepole pine dwarf mistletoe (*Arceuthobium americanum* Nutt. ex. Engelm.) is a native, parasitic, seed plant that is the most damaging disease agent in lodgepole pine. In addition to the impacts noted, dwarf mistletoe reduces vigor, growth and seed production of the host trees. It further reduces regeneration by infecting understory lodgepole pines, which are more likely to be killed if infected when small. Generally, dwarf mistletoe occurs twice as frequently on ridges and hillsides than on bottom sites. The upper elevation limit of lodgepole pine dwarf mistletoe in northern Wyoming is about 9,200 feet. Research has not consistently shown an association of mountain pine beetle with mistletoe-infected lodgepole pines.

Several white pines, tentatively identified as limber pine, were infected by a dwarf mistletoe species. The mistletoe species was presumed to be limber pine dwarf mistletoe, *Arceuthobium cyanocarpum*, but was not positively identified. This parasite results in severe

limber pine mortality and is second only to white pine blister rust in disease-caused damage among high-elevation western 5-needle pines.

Douglas-fir beetle

Douglas-fir beetle activity was not widespread across the assessment area. Epidemic levels of beetle-caused mortality appeared restricted to stands and areas dominated by Douglas-fir. Isolated Douglas-fir in mixed stands had not been attacked by July 16 when field work ended.

Walk through surveys did not include many sites dominated by Douglas-fir. Additionally, a few of these surveys were conducted before Douglas-fir beetle began attacking trees in 2003 (see example near the end of Inventory Plot section above). However, walk through surveys showed that significant mortality from Douglas-fir beetle attacks in 2003 was occurring in lower elevation portions of the assessment area. These sites were characterized by a high percentage of Douglas-fir in dense arrays of larger size classes. Personal communications from Jan Burke (USDA Forest Service, Rocky Mountain Region, National Fire Plan Silviculturist) added many similar observations to this scenario, especially near Hidden Lake in the Marquette Creek drainage. Either the extensive and intense Douglas-fir beetle epidemic centered in the North Fork of the Shoshone River drainage (Schaupp et al. 2002) has recently made its way to Carter Mountain or another intense Douglas-fir beetle epidemic is just beginning where there are highly susceptible stands and areas.

In contrast, many large cone-bearing Douglas-fir were located in the Marquette and Carter Creek drainages and none of them had been attacked by Douglas-fir beetle. For example, 50 large diameter Douglas-fir were closely examined on July 10 during walk throughs from the access off Carter Ranch to the west through location 437202. None of these trees had been attacked, nor were older attacks evident on other Douglas-firs. It is unlikely that Douglas-fir beetle will attain the extreme population levels displayed by the more aggressive spruce beetle, because there is less food in the area and it is more scattered. Therefore, it is also likely that these more isolated Douglas-fir will survive.

CONCLUSIONS

Concurrent epidemics of spruce, mountain pine, and Douglas-fir beetles in the same area is at best extremely rare. This is the situation in the Carter Mountain assessment area, although each beetle epidemic is in a different phase.

A very intense and extensive epidemic of spruce beetle began west of the Continental Divide, which was discovered in 1999 on northwestern portions of the Shoshone National Forest and adjacent lands. Epidemic beetle populations made their way to the east, arriving around the year 2000 in the Carter Mountain assessment area. By the fall of 2003 or 2004, the spruce beetle epidemic will have run its course through the forests there, resulting in the death of almost all of the Engelmann spruce larger than 5 inches DBH and some smaller diameter trees. This mortality has occurred everywhere, regardless of tree density or species composition of the sites in which the attacked spruce had been living.

Because the spruce beetle has killed much of the overstory, the remaining live forest canopy is composed primarily of lodgepole, limber, and white bark pines and Douglas-fir, with some subalpine fir and a smaller amount of aspen. Beetle epidemics in the pines and Douglas-fir threaten to further reduce the forest cover and degrade stands managed for fiber production.

Mountain pine beetle is killing the white pines in many areas on Carter Mountain. Populations have

been at epidemic levels since 2002, at least, and show signs of increase in 2003. The level of pine mortality to date is far below that of the spruce beetle and is concentrated in areas of dense, larger white pines. Mountain pine beetle populations have begun to attack lodgepole pine, adjacent to and a long ways from beetle-infested white pines. This situation, MPB-infested white pine adjacent to susceptible lodgepole pine, occurs in several locations within the assessment area. It constitutes a special hazard to the lodgepole pines, because of superior beetle reproduction in white pines and the beetles' habit of switching from white pines to another host.

Large-scale MPB epidemics are actually the culmination of many smaller, local episodes of MPB-caused mortality. With favorable conditions, the situation in the assessment area is only a few years away from such an occurrence, because the food base is present and the beetle population is expanding locally. As with all tree-killing bark beetles, preventing large-scale epidemics through a regular regimen of forestry practices over time that result in mixed stands in various age classes, is far more effective, efficient, and long lasting than trying to suppress an on-going, widespread epidemic, which often quickly becomes unmanageable.

While the spruce beetle is the most aggressive of the three tree-killing bark beetles, much of the remaining green forest canopy in the assessment area is lodgepole pine and it is at risk of significant mortality in the near future from mountain pine beetle, if no management actions are undertaken. There is an opportunity to either prevent or reduce the impact on lodgepole pine from mountain pine beetle, dwarf mistletoe, and comandra blister rust that has a reasonable chance of success if action is taken soon.

The Douglas-fir beetle epidemic situation appears more advanced than that of the mountain pine beetle, yet is still far short of the current spruce beetle episode. Mass attack in 2003 on nearly all trees in an area is a clear sign of a large, aggressive Douglas-fir beetle population. It may not be possible to prevent the Douglas-fir beetle epidemic from impacting most of the denser, larger-diameter, more pure stands and areas of Douglas-fir, however the risk to individual trees can be reduced.

In areas where land management objectives are threatened by mortality of mature Douglas-fir, actions can be taken that protect individual trees, groups of trees or stands. It is likely, for example, that isolated Douglas-firs across the assessment area will not be located and killed by Douglas-fir beetle. Reducing the Douglas-fir beetle population via sanitation will assist in this. Thinning will reduce the food base and blunt subsequent population increase. Where wood products are the management objective, presalvage can capture the full value and use of Douglas-fir before the beetles and associated fungi degrade the wood. In addition, silvicultural treatment would help mitigate future mortality from DFB by altering the conditions that facilitate tree killing by the beetles.

If done on a sufficient scale over enough time, silvicultural practices that create a mosaic of forest age class and a mixture of species should reduce the size of the next beetle epidemic. This is true for all three beetle species discussed.

White pine blister rust, an exotic fungus-caused disease, presents a special, long-term challenge to the presence and distribution of whitebark and limber pines due to the mortality it causes. Because it is an exotic organism, host trees have had little time to develop or express any natural resistance in their populations. Furthermore, the tools available to combat this disease are few and mostly untested. Training staff to recognize this disease, to detect potentially resistant individuals, and then to protect them will be increasingly important.

PEST MANAGEMENT STRATEGIES

Available pest management strategies for dealing with the mountain pine and Douglas-fir beetles will need to focus on prevention (the reduction of susceptible hosts and new beetle attacks), and suppression (direct action that kills beetles). Methods available under each strategy are presented and briefly discussed. Not all methods are appropriate or effective in every circumstance. The decision to employ a particular strategy or combination of strategies should be predicated upon consideration of management objectives, stand conditions and location, economics, social and aesthetic values, and other factors. Where mountain pine and Douglas-fir beetles are considered pests and where action is warranted, the following strategies are available:

Strategy 1: Reduction of susceptible hosts

This is the only long-term strategy that addresses the fundamental cause of MPB and DFB epidemics, which is susceptible trees and stands.

Silvicultural treatment should be part of any ongoing vegetation management program to help increase the health of stands by decreasing their vulnerability to forest insects and tree diseases, not just to bark beetle attack. Factors that weaken tree defense, such as comandra blister rust or root disease, can predispose an area to bark beetle epidemics. Silvicultural treatment to reduce susceptibility to and mitigate potential mortality from mountain pine and Douglas-fir beetles can be used in stands either before or during beetle attack, although concurrent sanitation (see below) may be needed when treating during an epidemic. It is preferable, though not always possible, to undertake silvicultural treatments during periods of low beetle densities and lesser tree stress such as non-drought years.

Douglas-fir beetle

To reduce the susceptibility of stands to Douglas-fir beetle, basal area should be brought below 80% of normal stocking (Furniss et al. 1981). Harvesting in old, mature stands and thinning in very dense younger stands should significantly lower individual stand susceptibility to subsequent Douglas-fir beetle attack.

Trees become susceptible to the Douglas-fir beetle when the combination of stand density and tree size begins to exceed the carrying capacity of the site for water and nutrients (Shore et al. 1999). The proportion of Douglas-fir in a stand and its density are important regulators of susceptibility (Furniss et al. 1981; Negron 1998; Negron et al. 1999). In unmanaged stands, beetles attack older, larger trees in denser groups (Furniss et al. 1981). Silvicultural treatments that alter these stand conditions will reduce a stand's susceptibility and subsequent mortality (Schmid and Amman 1992; Schmitz and Gibson 1996). Thinning has been suggested as a means to manage forest stands to reduce losses to Douglas-fir beetle in the Pacific Northwest (Williamson and Price 1971). Furthermore, the proportion of susceptible stands across a large area should affect the potential size and intensity of Douglas-fir beetle epidemic by impacting beetle population mortality during dispersal and attack.

The resistance of live trees to bark beetle attack is the most important natural factor controlling epidemic development (Schmitz and Gibson 1996). In addition to silvicultural treatments to reduce tree and stand susceptibility, prompt treatment of large numbers of trees that lose their resistance to attack is important in preventing epidemic induction. Any method that renders the trees unsuitable to infestation or that kills beetles once they are within these trees will be effective (see methods in Strategy 2). The Douglas-fir beetle most successfully breeds in trees injured by wind, disease,

defoliation, fire or other agents. This increased reproduction allows populations to increase to such large levels that they then can overwhelm and kill otherwise healthy trees, signifying the onset of an epidemic. The best “control” of a Douglas-fir beetle epidemic involves long term, pro-active management to prevent its occurrence (Schmitz and Gibson 1996).

Mountain pine beetle in lodgepole pine

Actions that promote tree vigor and wide spacing are the primary means to reduce or prevent the impact of MPB epidemics (Amman et al. 1989). The most recommended long-term tactic to minimize losses to MPB is to partially cut susceptible stands or to harvest and subsequently replace susceptible stands. Removal of individual pines of low vigor and poor health, such as those afflicted by disease, will lessen the chance of a MPB outbreak.

Lodgepole pine stands at high risk to MPB are those at lower elevation-latitudes where average tree diameter exceeds 8 inches and average tree age exceeds 80 years (Amman et al. 1977). Partial cutting that reduces stands to 60 - 80 square feet of basal area or less and average tree diameter to below 8 inches reduces stand susceptibility to MPB. Of many examples, Amman et al. (1988) present results from the Shoshone National Forest showing good results in reducing infestation levels for at least five years from partial cutting. When partially cutting susceptible stands, care must be taken to avoid leaving dense pockets of mature pines, because these areas can serve as foci for MPB attack (McGregor et. al. 1987).

The risk of windfall must also be considered when partially cutting lodgepole pine stands. Soil depth and stand density contribute to wind firmness as does stand exposure. Alexander (1972) describes windfall risk based on exposure as follows:

Low Windfall Risk Situations

1. Valley bottoms except where parallel to prevailing winds and all flat areas.
2. All lower and gentle middle north and east facing slopes.
3. All lower gentle middle south and west facing slopes that are protected by considerably higher ground not far to windward.

Moderate Windfall Risk Situations

1. Valley bottoms parallel to the direction of prevailing winds.
2. All lower and gentle middle south and west facing slopes not protected to the windward direction.
3. Moderate to steep middle and all upper north and east facing slopes.
4. Moderate to steep middle south and west facing slopes protected by considerable higher ground not far to windward.

High Windfall Risk Situations

1. Ridgetops.
2. Moderate to steep middle south and west facing slopes not protected to the windward, and all upper south and west facing slopes.
3. Saddles on ridgetops.

Windfall risk is increased in the above situations by poor drainage, shallow soil and defective roots and boles

Acceptable partial cutting methods recommended to reduce a stand's risk to MPB include commercial thinning, shelterwood cutting, and overstory removal. Seed tree cuts are risky for lodgepole pine due to the likelihood of windfall. In stands that are lightly infested with MPB, all trees that are attacked may be removed along with the most susceptible trees without exceeding standard basal area prescriptions. Heavily infested stands can be addressed with greater partial cuts, but are generally not advised in lodgepole pine stands because of windthrow problems.

Clearcutting is also a useful tool to create conditions favorable to regenerating lodgepole pine and converting mature stands to younger stands. Block or patch cutting within extensive areas of pure even-aged stands of lodgepole pine can reduce the potential for MPB epidemics by reducing the area likely to be infested at one time. In addition, clearcutting is generally preferable to partial cutting in lodgepole stands that are understocked or heavily infested by dwarf mistletoe (Alexander 1974). Partial cutting is not recommended where the stand dwarf mistletoe rating (DMR) is above 3 (Hawksworth and Johnson 1989). Size and layout of cutting units in dwarf mistletoe-infected stands is important and discussed in Hawksworth and Johnson (1989).

Mountain pine beetle in white pines

Lowering stand susceptibility to MPB through reductions in stand density and average tree diameter, as stated above from lodgepole pine, are applicable to white pines.

In contrast to the situation with lodgepole pine, little quantitative information has been documented about the tree and stand susceptibility of whitebark and limber pines to mountain pine beetle attack. Perkins and Roberts (2001) performed a retrospective study on a mountain pine beetle epidemic in whitebark pine in central Idaho that yielded models for the probability of attack on trees and on stand susceptibility. Their tree-level model can be used to estimate anticipated cumulative mortality, given an MPB epidemic. Although from higher elevations, their study presents results that are more specific than, yet consistent with general field observations in the Carter Mountain assessment area and elsewhere. The following is based largely on Perkins and Roberts (2001).

Whitebark and limber pine stands become susceptible at lower basal areas than lodgepole pine. Stands carrying in excess of 44 ft²/acre of basal area or having a stand density index (SDI) exceeding 100 are most susceptible. While attacks on individual trees may occur at lower density, significant mortality can be expected when susceptible stands become attacked.

Characteristics of individual MPB-attacked trees show that diameter is positively correlated with probability of MPB attack. Diameters in excess of about 6 inches have a sharply higher probability of attack as diameter increases. The number of stems in a cluster is also positively correlated with increased attack probability.

Silvicultural treatments to white bark and limber pine that lower stand density, average tree diameter, and the number of trees per cluster will reduce susceptibility to and mortality from mountain pine beetle.

Strategy 2: Directly killing beetles

There is a variety of methods available to kill mountain pine and Douglas-fir beetles. Killing beetles directly addresses the symptom of the problem, which is too many beetles in one place at one time, and does not address the cause of the problem, which is susceptible tree or stand conditions. Direct control attempts are a short-term approach to beetle mitigation, unlike silvicultural treatments.

Sanitation harvesting involves removing currently infested trees from the site. Removal of beetle-infested trees can reduce the size of a localized beetle population. To be effective, sanitation harvesting should be completed before the beetles start to emerge in May (DFB) or July (MPB) of each year. Treatment may need to be repeated over several years, as some trees are always missed and immigration from untreated areas is possible. In addition to sanitation, in stands where mortality is already significant, salvaging dead trees to create desired reforestation conditions or to capture some economic value in the near future is often appropriate. However, salvage harvesting does not reduce beetle populations.

Currently infested trees can be located and treated mechanically to kill beetles developing within them prior to brood maturation and emergence. This is similar to sanitation, but employed on a smaller scale. A variety of methods can be used for mechanical treatment, including peeling bark, chipping, burning, solarizing, burying, or hauling infested trees at least one mile from the nearest host type.

Prescribed fire has been used as a short term mountain pine beetle control in some wilderness areas and Provincial Parks of Canada with mixed results. Success has depended upon a sufficiently intense crown fire so that the stems of infested trees are blackened. Attempts from 1995 – 1997 in Tweedsmuir Park resulted in one successful burn where mountain pine beetle populations were reduced by 50%. This information is available on the Internet at http://www.pfc.cfs.nrcan.gc.ca/entomology/mpb/management/fire/short_e.html.

Douglas-fir beetles are strongly attracted to down trees such as those blown over by wind. Trap trees take advantage of this attraction by deliberately luring beetles that are then killed. To be effective, trap trees must be relatively fresh. If the trap trees become infested, they must be treated before the brood matures. A variation of this method involves applying insecticide to the trap tree before it is attacked, which will kill incoming beetles before they can infest the trap tree.

Strategy 3: Prevention of new beetle attacks

Douglas-fir beetle has a well-studied complex of pheromones, airborne behavior-modifying message-bearing chemicals. Anti-aggregation pheromones, such as MCH (3-methylcyclohex-2-en-1-one), serve to regulate the density of beetle attacks by disrupting the aggregation behavior of beetles (Schmitz and Gibson 1996). MCH has been used experimentally and operationally to reduce the level of attack in high-risk areas (Ross and Daterman, 1994, 1995; Ross et al. 2001). It has been used successfully to protect areas from less than an acre to 300 acres (see Schaupp et al. 2003 for a local example).

Several insecticides are registered for use that can prevent infestation when applied properly prior to mountain pine or Douglas-fir beetle attack. For large trees, specialized application equipment is needed. Lack of operational experience and the demonstrated success of MCH make this tactic most appropriate for use on lethal trap trees for Douglas-fir beetle. Years of operational success and inconsistent results with the anti-aggregation pheromone(s) for mountain pine beetle mean that preventive insecticide is the preferred method for this beetle species.

It is possible that pruning off the lower branches of white pines will reduce their susceptibility to MPB attack by providing a less favorable microhabitat. This action will also lower the shade and moisture available to *Ribes* spp. plants, the alternate hosts for white pine blister rust, frequently found growing at the base of white pines. This will create less favorable conditions for fungal intensification on *Ribes* spp. and infection of pines (Arno and Hoff 1990). Basal pruning would be most appropriate on individual white bark pine of high value, due to the expense.

RECOMMENDATIONS

1. Develop a long-term strategy to deal with impacts of the bark beetle epidemics and white pine blister rust.

It is appropriate to look at larger, landscape-level projects for the future. Management area emphases and other land management goals may be affected in ways unanticipated before these bark beetle epidemics became so intense and widespread. Estimates of mortality and infestation probability can be determined on a stand-by-stand basis and compared with the stated objectives to provide impact predictions, regardless of which strategy or strategies are taken. Having a sound management plan for large areas will only help to provide for the future forest and the needs of the people.

The presence and expected increase in the impact from white pine blister rust is of concern. Throughout the Rocky Mountain and intermountain west, the decline of white pines is receiving attention. White pine blister rust is thought to be a major factor in this decline. Training field staff to recognize white pine blister rust and to identify trees showing resistance to it will help protect white bark and limber pines. The use of prescribed fire in white pine stands will create openings for natural regeneration and reduce stand densities, lowering between tree competition and susceptibility to mountain pine beetle attack. Prescribed fire may create conditions less favorable to *Ribes* spp. The expected response of *Ribes* spp. to fire needs to be taken into consideration, as it is an essential link in the life cycle of white pine blister rust. Efforts to reduce *Ribes* spp. near white pines may be effective in mitigating white pine blister rust impacts, but only if this is thorough.

2. Use aggressive silvicultural treatments in the short-term.

In the immediate future, aggressive use of silvicultural options such as partial cutting or thinning uninfested stands and sanitation in infested stands in the assessment area should be done to the extent possible. These treatments should be undertaken as soon as possible in order to protect the remaining forest cover from additional tree-killing bark beetle epidemics, currently on the rise. This is especially important where white pine stands, currently infested by mountain pine beetle, are adjacent to susceptible lodgepole pine stands and where heavily infested Douglas-fir stands are near mixed stands where relatively isolated Douglas-fir are expected to contribute seed to the future forest..

Additional, more specific recommendations are as follows:

- Reduce the susceptibility of lodgepole pine stands and sanitize trees currently infested by mountain pine beetle and infected by comandra blister rust and dwarf mistletoe.
- Reduce the susceptibility of white pine stands and sanitize trees currently infested by mountain pine beetle.
- In the absence of stand-level treatments, undertake direct control methods in white pines to reduce the local mountain pine beetle population.
- Implement treatments to start new age classes in pines and Douglas-fir, both diversifying the forest and conserving genetic resources of threatened host trees, especially where dwarf mistletoe heavily infects pines.
- If white pine losses threaten wildlife, watershed or other resource management objectives, consider measures such as the following: preventive insecticide spraying and/or pruning the

branches from the base of white pines to mitigate against mountain pine beetle; grubbing out or herbiciding the *Ribes* spp. to mitigate against white pine blister rust; prescribed fire to create openings, stimulate regeneration and reduce inter-tree competition and bark beetle susceptibility; and collecting white pine seed to preserve locally-adapted genetic resources should replanting become necessary.

3. Provide interpretation to the public and information to prevent moving infested firewood.

The impact of spruce beetle is obvious and dramatic to anyone who visits Carter Mountain. This presents an excellent interpretive opportunity to explain what is happening and to describe the ecological role of tree-killing bark beetles.

Given the extensive beetle-caused tree mortality and the long-standing use of Carter Mountain for firewood cutting, the potential exists for unintended movement of bark beetle-infested trees. It is recommended that information be distributed with firewood permits and perhaps posted on Carter Mountain to inform the public of this possibility and to prevent its occurrence.

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